AD-767 904

A STATISTICAL STUDY OF GRIP RETENTION FORCE

Theodore W. Horner, et al

Payne, Incorporated

Prepared for:

Aerospace Medical Research Laboratory

May 1973

AMRL-TR-72-116

AD 767904

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PAYNE, INC.

ANNAPOLIS, MARYLAND

MAY 1973

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AIR FORCE/56780/28 July 1973 — 100

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Payne, Incorporated 2200 Somerville Road Annapolis, Maryland 21401	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

A STATISTICAL STUDY OF GRIP RETENTION FORCE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report, June 30, 1971 - March 2, 1973

5. AUTHOR(S) (First name, middle initial, last name)
Dr. Theodore W. Horner
Fred W. Hawker

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1973	39	2

8a. CONTRACT OR GRANT NO. F33615-71-C-1892 b. PROJECT NO. 7231 c. Task No. 723106 d.	9a. ORIGINATOR'S REPORT NUMBER(S) Working Paper No. 101-11 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AMRL-TR-72-110

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Aerospace Medical Research Laboratory, Aerospace Medical Div., Air Force Systems Command, Wright-Patterson AFB, Ohio

13. ABSTRACT

To assess an ejection seat occupant's ability to hold on to a handle, the data from the two-handed force retention capability tests of Garrett, Alexander and Bennett are analyzed to produce curves of "probability of letting go" as a function of force. Two curves are produced; one for "double grip handles," comprising a T-Bar and a Twin Grip; and one for "Rings," comprising a flexible loop and the familiar, rigid D-Ring.

It is concluded that, at the force levels experienced in most present-day ejections, which occur at low and moderate air speeds, the probability of letting go a ring is an order of magnitude greater than for a double grip handle. It is concluded that handle design strongly influences the probability of letting go, and therefore the probability of arm flail injury.

DD FORM 1 NOV 65 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Ejection Seats						
Limb Flailing						
Aircraft Safety						
Handle Design						
Grip Retention Force						

Security Classification

SUMMARY

In the study of arm "flail" injury in open ejection seats, it is important to know the probability of a crew member being able to hold on to a handle, such as a D-ring, when aerodynamic forces acting on his arms are tending to pull his hands off the handle.

In this report, the data from the two-handed force retention capability tests of Garrett, Alexander and Bennett are analyzed to produce curves of "probability of letting go" as a function of force. Two curves are produced; one for "double grip handles," comprising a T-Bar and a Twin Grip; and one for "Rings," comprising a flexible loop and the familiar, rigid D-ring.

The concept of the "probability of letting go" introduced in this report is believed to be a new concept in the field of handle design. Hitherto, the effect of handle configuration on "force retention capability" has been studied in terms of mean force retention, and the differences have not been large; 400.2 lb for the double grip handles in this study, as compared with 331.2 lb for the rings, for example; an improvement of only 21%. But, the force levels experienced by an ejecting crew member are generally much lower than these figures, thus one is concerned with comparing probabilities in the tails of the ring class and twin class distributions. In this region, the probabilities are substantially smaller for the twin grip distribution as compared to the ring class.

We are forced to conclude that, so long as present pre-escape procedures of slowing the aircraft before ejection are used, replacing existing D-rings with twin grip handles would reduce arm flail injury as an operational problem. We also conclude that additional experimental work, of the type pioneered by Garrett et al, using not only different handle configurations, but also different handle locations with respect to body axes, could be very rewarding, provided that statistical data analysis techniques are used.

FOREWORD

The research documented in this report was performed in partial fulfillment of Contract No. F33615-71-C-1892. The study was accomplished by Payne, Incorporated, 2200 Somerville Road, Annapolis, Maryland 21401. Peter R. Payne was the Principal Investigator.

The Air Force Technical Monitor was James W. Brinkley of the Impact Branch, Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory. The work was performed in support of Project 7231, "Biomechanics of Aerospace Operations," Task 723106, "Impact Exposure Limits and Personnel Protection Criteria."

This study was funded by the Life Support Systems Program Office of the Aeronautical Systems Division (AFSC) at Wright-Patterson Air Force Base, Ohio.

This technical report has been reviewed and is approved.

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Director
Biodynamics and Bionics Division
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SECTION I

INTRODUCTION

In the experiments reported in reference 1, the subject sat in an ejection seat and grasped a handle. Four types of handles were used:

1. The conventional D-ring 2. A "Gemini Flexible Loop"	Both rings
3. A "Twin Grip" 4. A T-Bar	Both with separate grips for each hand

The handle was connected to a pneumatic system that was adjusted to give a particular force pulling the handle away from the subject, and which came into play as soon as the subject pulied on the handle to release a lock. The subject held on to the handle as long as possible, and the time at which he let go (if less than 30 seconds) was recorded.

The authors kindly made the original data sheets available, and this information is reported in Appendix I. It will be noted that incomplete data are given for two additional subjects, 10 and 11, not reported in reference 1.

NATURE OF THE DATA

Apart from some data gaps, each grip was tested with each of eleven subjects. In the testing of each grip, a force was selected and then the time observed at which the grip was released. From an experimental standpoint, force can be regarded as the independent variable and time as a dependent variable. The data on each subject-grip consisted of pairs of observations on force and time. The purpose of the analysis was to determine, within the limitations of the data, whether the grips might be different and if so, which might be best. A typical set of raw data is shown in table 1.

Table 1. Typical Set of Raw Data
(Twin Grip, Subject 1)

Force (lb)	Log_{10} Force (Independent Variable)	t = Retention Time (sec) (Dependent Variable)
200	2.30103	26.75
220	2.34242	13.00
257	2.40993	15.75
255	2.40654	16.50
275	2.43933	5.25
300	2.47712	4.25
325	2.51188	1.25
320	2.50515	0.75

SECTION II

MODEL

The statistical model

$$t = A + Bx + e \quad (1)$$

was fitted to the data for each subject-grip combination, where there was at least six observations per subject and where

t = time at which the subject let go, in seconds

x = $\log_{10}$ force in pounds

e = a random error with zero mean and variance σ^2

A = the intercept

B = the slope

For each subject-pair combination fitted, it was possible to estimate the unknown constants of the model; namely, A, B and σ^2, along with their standard errors and confidence limits.

MODEL ASSESSMENT

A particular example of application of the model to a subject-grip combination is shown in figure 1 for the twin grip-subject 1 combination. From this graph the points cluster about the model line very well, the correlation of time and log force being 0.92. Other correlations are tabulated in Appendix II, tables 1, 2, 3 and 4. The average correlations across subjects for the several grips are set out below.

Grip	Average Correlation	Correlation for all Data Combined
Twin Grip	0.91	0.65
T-Bar	0.87	0.67
D-Ring	0.88	0.58
Gemini Loop	0.90	0.58

When the data for all subjects is combined and the correlation obtained for time and log force at time zero, the correlation is found to be much reduced. For example, for the twin grip, the average correlation is found to be 0.91. The correlation obtained, however, by simply pooling the data across subjects is only 0.65. The fact that this latter correlation is substantially less than the former indicates that the subjects have differing slopes. As a result, the distribution of slopes among subjects becomes of interest. In particular, interest centers in the mean slope and in the variation in slope from one subject to another.

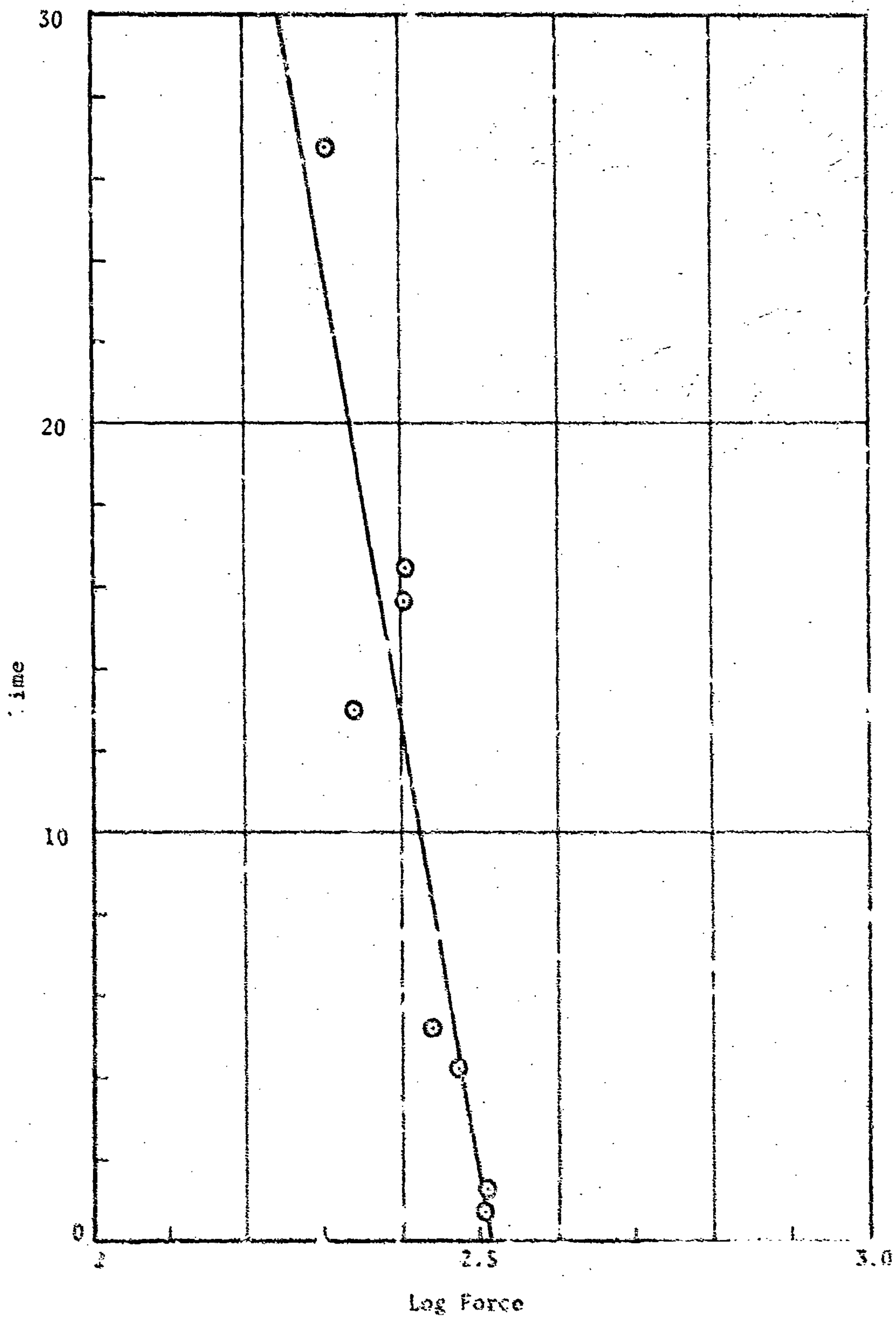

Figure 1. Typical Time Versus Log Force for Twin Grip Retention Data.

REVISED MODEL

The intercept A of the model is that retention time for which log force is zero; that is, when force is one pound. Thus, the intercept is associated with a force far removed from the observed force data. To circumvent this difficulty, log force at zero retention time has been employed; that is, that log force which instantaneously snaps the grip out of the subject's hands.

The log force at time zero can be estimated as

$$\hat{x}_o = -\hat{A}/\hat{B}$$

where $\hat{A}$ and $\hat{B}$ are estimates of the intercept and the slope.

The prediction model for retention time

$$\hat{t} = \hat{A} + \hat{B}x$$

can be rewritten as

$$\hat{t} = \hat{B}(x - \hat{x}_o)$$

and this will be the form that will be employed throughout the remainder of the study. Referring to figure 1, the model is basically a hinge model with the hinge located at x_o and opened by an amount B.

SECTION III

SLOPE AND x_o STATISTICS

The slope and x_o statistics for the various subject-grip combinations have been tabulated in Appendix II, tables 1, 2, 3 and 4, along with other summary statistics. Average values for the four grip types, along with 95% confidence limits have been set out in table 2 below. This is a condensed version of Appendix II, tables 6 and 7.

Table 2. Average Slope and x_o Statistics

	Slope (B)			Log Force at Time Zero (x_o)		
		95% Confidence Limits			95% Confidence Limits	
Grip	Point Estimate	Lower	Upper	Point Estimate	Lower	Upper
Twin Grip	-122.1	-162.4	-81.8	2.589	2.534	2.644
T-Bar	-91.6	-122.7	-60.4	2.615	2.542	2.688
D-Ring	-46.3	-63.7	-28.7	2.532	2.443	2.621
Gemini Loop	-67.3	-92.6	-42.0	2.507	2.427	2.588

Taken as a whole, the data does suggest that the two grips within a class are essentially alike and, therefore, it appears reasonable to combine the data on the grips within a class so as to obtain the best estimates associated with each class. The method of combination was simply to average for each individual, the two slopes associated with the two grips within a class. Similarly, this was done for the log force at time zero. The data for each grip class is shown in table 3.

Table 3. Slope and x_o Data on Grip Class

	Twin		Ring	
Subject	Slope	x_o	Slope	x_o
1	-100.7	2.5226	-57.7	2.4280
2	-120.5	2.5486	-39.19	2.4589
3	-81.9	2.6504	-43.77	2.4511
4	-95.6	2.5481	-48.13	2.5030
5	-84.6	2.5684	---	---
6	-72.5	2.7195	-38.91	2.7150
7	---	---	-99.35	2.5409
8	-137.6	2.6461	---	---
9	-231.2	2.6151	-104.65	2.5557
10	---	---	-49.33	2.5083

CORRELATION OF THE SLOPE AND LOG FORCE AT TIME ZERO

An interesting side question concerns the relationship between the slope and x_o statistics. Information on this point was obtained by correlating the slope and x_o statistics across individuals. The data employed for these correlations is that of table 3. The correlations for the Twin and Ring classes respectively were found to be 0.05 and 0.07. Since both are small and non-significant, there appears to be no evidence in the data of any relationship between slope and log force at time zero.

SECTION IV

COMPARISON OF GRIP CLASSES

Examination of table 2 indicates that the four grips can be grouped into two classes as shown below:

Class	Grip
Twin	T-Bar Twin Grip
Rings	D-Ring Gemini Loop

This grouping is clearly seen in figure 2, where lines based on the point estimates of the B and x_o statistics have been plotted for the four grip models.

Estimates were made of the mean differences in the slope and x_o statistics for members of each pair. These estimates, along with 95% confidence limits are shown below. Table 4 is condensed from Appendix II, table 10.

Table 4. Comparison of Grips Within a Class

Comparison	Point Estimate of Difference Within Class	95% Confidence Limits Lower	95% Confidence Limits Upper	Point Estimate of Difference Within Class	95% Confidence Limits Lower	95% Confidence Limits Upper
Twin Grip minus T-Bar	-14.97	-44.87	14.93	-0.0299	-0.068	0.008
D-Ring minus Gemini Loop	16.5	-.38	33.38	0.0294	-0.013	0.071

All of the 95% confidence intervals in table 4 bracket zero. This shows that there is little evidence of real differences in the slope and x_o statistics among grips within classes.*

---

* In this particular instance, the test of the null hypothesis that the mean difference is zero by means of the confidence interval test is only approximate. A more exact test using the statistic computed as the ratio of the observed mean difference to the standard error of this difference confirms conclusions developed from the confidence interval test procedure with one exception. The exception is the comparison of the slopes for the D-Ring and Gemini Loop. The test statistic in this instance just barely achieves significance at the five percent level. Since, as will be shown later, these two grips are decidedly inferior to the Twin Grip class, it did not appear worthwhile to treat the two ring grips separately in subsequent analysis.

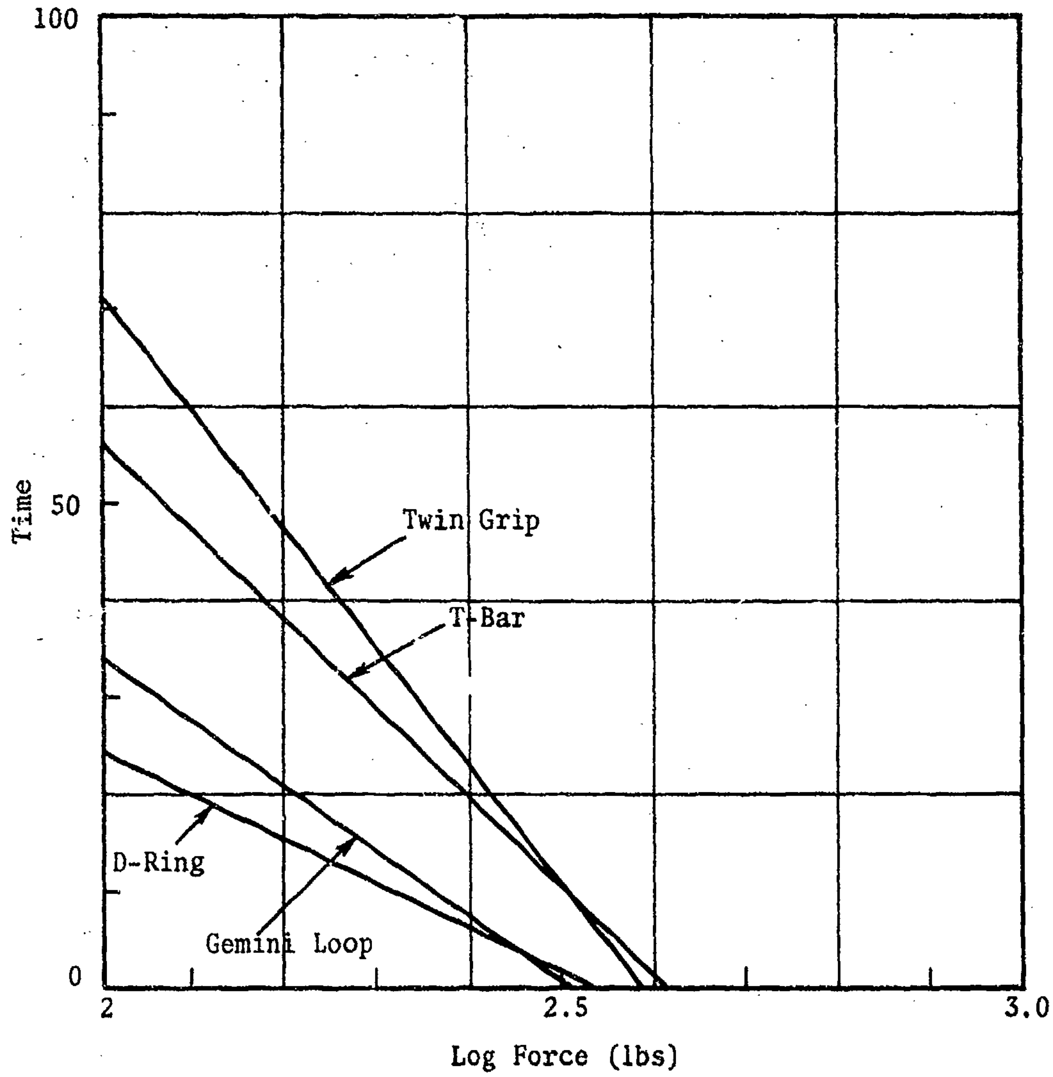

Figure 2. Comparison of Slopes and Log Force at Zero Time for the Four Grip Types.

Estimates of mean differences in the slope and x_o statistics, along with 95% confidence limits, are set out in table 5 below for the two grip classes. The mean difference was calculated by obtaining differences for each individual using the data of table 3 and then taking the average.

Table 5. Comparison of Grip Classes

Statistic	Point Estimate of the Mean Difference	95% Confidence Limits Lower	Upper
Slope	-61.7	-99.5	-23.9
x_o	0.082	0.013	0.151

Since neither confidence interval overlaps zero, the slopes and x_o statistics for the two classes are different. Hence, it is meaningful to have separate estimatos for each class. These separate estimates are set out in table 6 below.

Table 6. Estimates for Each Grip Class

	Point Estimate	95% Confidence Limits Lower	Upper
Twin:			
Slope	-115.6	-158.4	-72.6
x_o	2.60	2.54	2.61
Ring:			
Slope	-60.1	-82.3	-37.9
x_o	2.52	2.44	2.60

Figure 3 displays the time-log force relationships for the two grip classes based on the data of table 6.

PREDICTION OF RETENTION TIME

The equation

$$\hat{t} = \hat{B}(x - \hat{x}_o) \tag{2}$$

can be employed to estimate the retention time associated with a particular log force. Ideally, the values employed for B and x_o would be those appro-

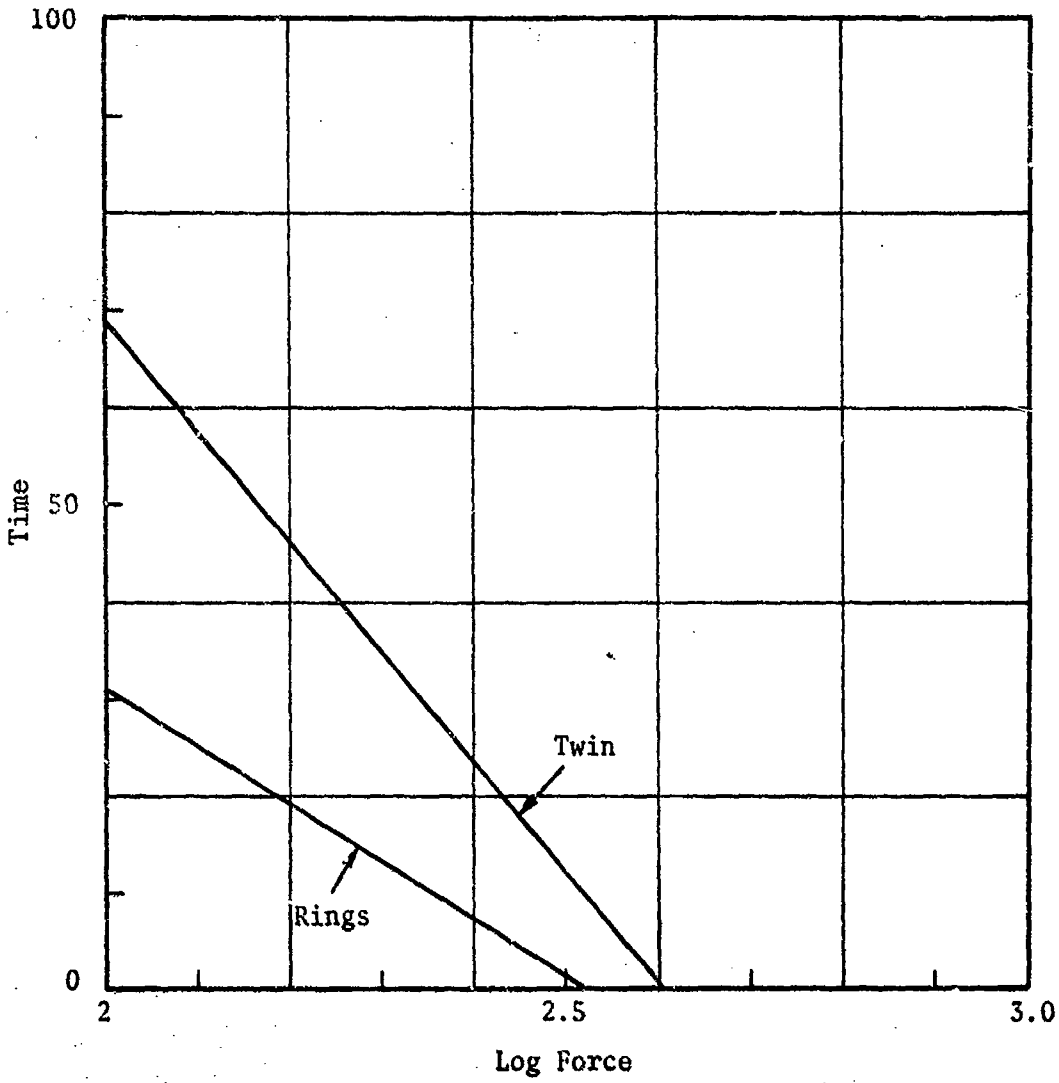

Figure 3. Plot of Time Versus Log Force (Log Force > 2) for the Two Types of Grips Using the Mean Values of Table 12, Appendix II.

priate to the subject in question. In practice, when the above prediction equation is employed, the values of B and x_o appropriate to the subject will not be known. One assumes that the subject in question is a random member from a population of subjects similar to that from which the sample data were drawn. The best estimate then of the B and x_o values for the individual in question becomes the mean B and x_o values. These latter are given in table 6 for the two types. The logic of this procedure is further supported by the discussion of the correlation of the slope and log force at time zero, wherein it was shown that slope and log force at time zero are uncorrelated.

Conversely, equation (2) on page 9 can be employed to estimate the log force that is associated with a particular retention time. The estimating equation is

$$\hat{x} = (1/\hat{B})\ t^* + \hat{x}_o$$

where t* is the specified retention time. A special case of the above equation is the case of t* = 0; in this case the estimated log force is simply x_o, the log force at zero retention time.

TOLERANCE INTERVALS

Because the values of B and x_o do differ among random subjects, the extent of such variation becomes of interest. Tolerance intervals provide a basis for judging the extent of this variation. Tolerance intervals must be distinguished from confidence intervals. The latter relate to the uncertainty in the estimation of a population parameter. Thus, one may have a confidence interval which displays the uncertainty as to where the center of the population is located. The tolerance interval, on the other hand, provides limits wherein one would anticipate that a specified fraction of the population might lie. Set out in table 7 are values (one-sided tolerance intervals with 90% confidence) such that one would anticipate that 95% of the population slopes would be less extreme than the tabular value. Similarly, one would expect 95% of the x_o statistics to be greater than the tabular value.

Table 7. Ninety Percent Tolerance Intervals That Include 95% of the Population Values

Class	Statistic	90% Tolerance Level
Twin		
	Slope	-257.0
	x_o	2.7870
Ring		
	Slope	-133.3
	x_o	2.7689

EFFECTS OF AGE

One of the likely causes for differences among subjects with respect to slopes and x_o is age. To examine this question, slopes and log force at time zero were both correlated with age. The correlations, which are shown in table 8, were found to be small and non-significant at the five percent level. Although the data does not support any relationship with age, such a relationship should not be ruled out, since the number of subjects employed to develop the sample relationship was so small; *namely*, eight.*

Table 8. Correlations of Slope and x_o With Age

Class	Statistic	Correlation**
Twin		
	Slope	0.29
	x_o	0.59
Ring		
	Slope	0.49
	x_o	0.57

PROBABILITY OF LETTING GO

A probability of letting go of the grip versus handle force is developed from the mean and standard deviation values (Appendix II, table 15) and presented in figure 4. Figures 5 and 6 show the variation in the probability of letting go at 0, 5 and 10 seconds. The grip retention capability is reduced with time.

* The literature (for example reference 2) shows that, in general, muscle force falls off with increasing age after 20-25 years.

** A correlation of at least 0.71 is required for significance at the five percent level.

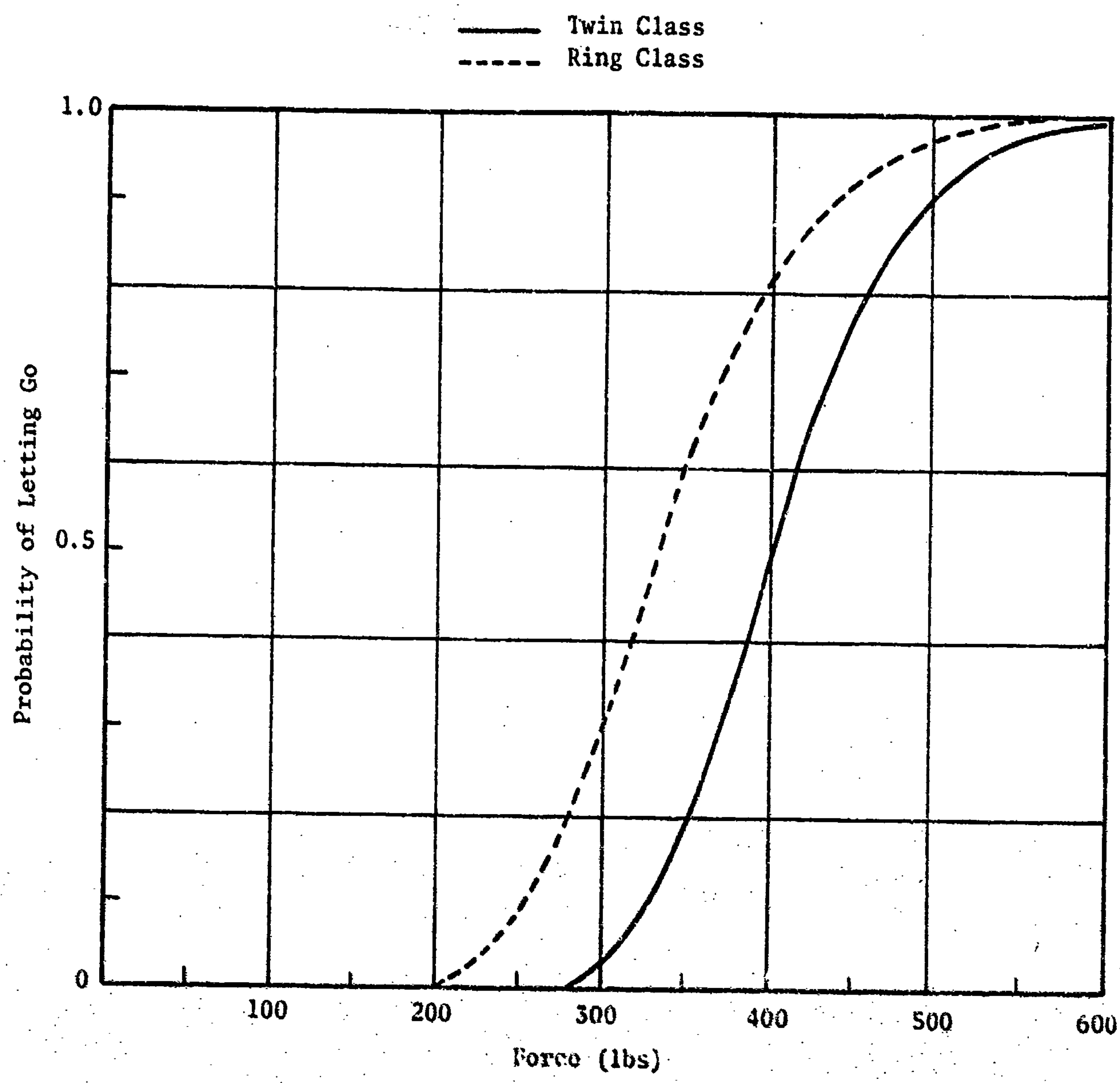

Figure 4. Probability of Letting Go for the Twin Class and Ring Class Grips at Time Equal to Zero.

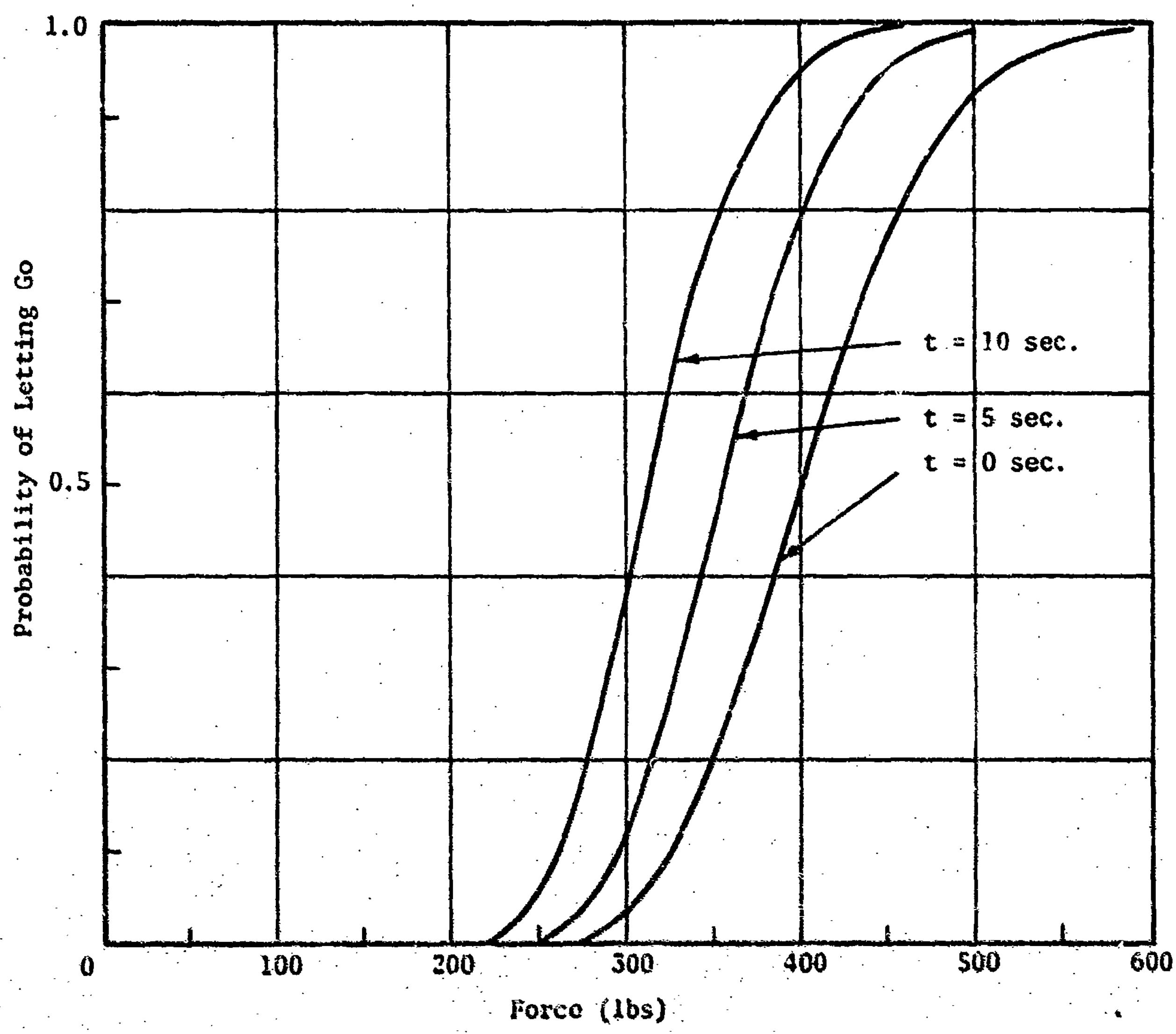

Figure 5. Probability of Letting Go as a Function of Time for the Twin Class Grips.

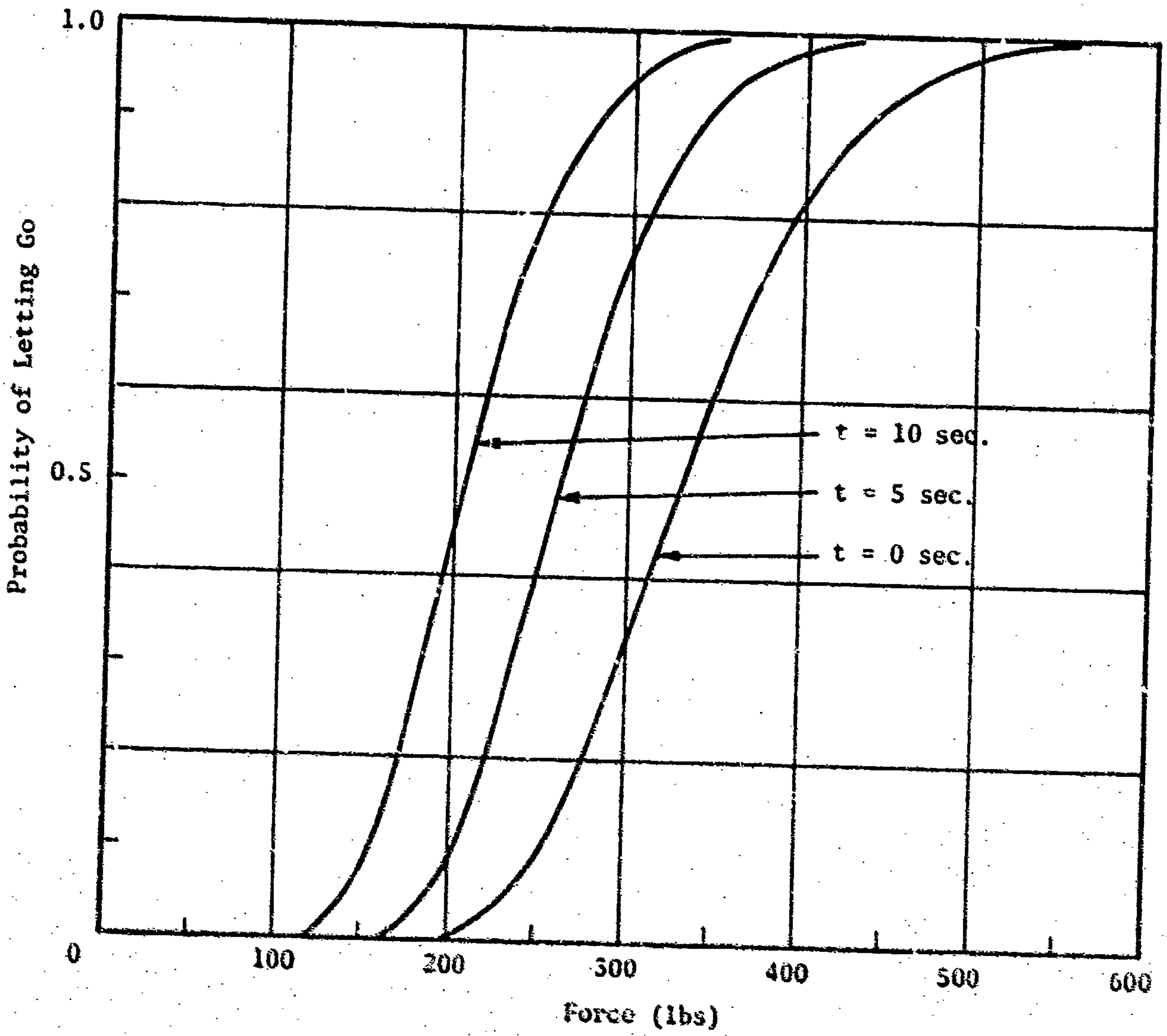

Figure 6. Probability of Letting Go as a Function of Time for Ring Class Grips.

SECTION V

CONCLUSIONS

When a crew member escapes from an aircraft in an open ejection seat, he is typically holding on to a D-Ring with both hands. If the wind blast forces on his arms are large enough to pull his hands off the D-Ring, his arms will blow back with the airstream, and "flail injury" may result. It is, therefore, important to know the "probability of letting go," as a function of force. Such a probability distribution is derived in this report, from the experimental data of Garrett et al, believed to be the only such data available.

Despite the relative paucity of data, "twin grip" handles are clearly superior to the two "ring" type handles tested, and it is possible to produce the required "probability of letting go" distributions for both classes.

APPENDIX I

RAW DATA OF GRIP RETENTION

TIME VERSUS FORCE

by

John W. Garrett, Milton Alexander, and William G. Bennett

NOTE: In the tables which comprise this Appendix, for each handle, the first column gives the load in pounds, and the second, the time (in seconds) at which the subject let go.

Table I-1. Raw Data - Subject 1

Twin Grip		Gemini Loop		T-Bar		D-Ring	
200	26.75	110	20.5	200	28.25	135	3.25
220	13.00	125	27.0	230	12.75	135	11.50
257	15.75	140	17.0	248	8.25	130	25.25
255	16.50	175	5.75	272	4.25	155	20.5
275	5.25	195	4.0	292	3.25	180	18.75
300	4.25	235	0.5	300	1.0	210	5.25
325	1.25	233	0.33	320	2.75	225	1.75
320	0.75	275	1.25	335	0.75	240	0.75
350	N.H.	300	N.H.	350	0.25	300	1.0625
				370	1.125	325	N.H.
				400	N.H.		

N.H. - No Hold

Table I-2. Raw Data - Subject 2

Twin Grip		Gemini Loop		T-Bar		D-Ring	
235	26.75	105	21.5	190	28.25	125	12.5
243	17.5	125	14.5	210	28.75	145	9.75
275	13.0	145	12.0	240	21.5	175	7.5
310	4.0	175	13.0	280	8.75	210	3.5
335	2.0	210	3.75	305	6.0	225	3.0
335	2.75	240	3.25	310	7.4	250	2.0
365	0.4	280	1.50	350	2.3	280	0.7
370	N.H.	300	0.4	360	N.H.	300	N.H.
		325	N.H.				

Table I-3. Raw Data - Subject 3

Twin Grip		Gemini Loop		T-Bar		D-Ring	
215	22.0	140	18.0	235	17.25	110	17.0
225	18.5	180	7.25	260	22.0	135	15.75
260	14.5	205	8.0	280	27.0	155	10.25
250	23.25	170	7.25	270	27.0	165	6.75
330	9.0	250	1.50	330	8.5	235	1.5
375	4.75	310	1.0	360	5.3	265	0.4
380	5.10	325	N.H.	370	4.1	290	0.6
435	2.4			400	6.0	300	N.H.

Table I-4. Raw Data - Subject 4

Twin Grip		Gemini Loop		T-Bar		D-Ring	
250	15.0	150	10.75	235	14.0	190	14.5
275	2.9	180	18.0	275	18.0	180	13.25
300	2.75	200	7.25	300	8.0	225	3.75
315	0.45	225	3.0	325	4.1	245	8.75
315	0.8	250	3.5	350	2.1	270	4.25
325	0.6	280	1.0	375	1.9	300	4.0
350	N.H.	300	N.H.	380	1.3	335	0.9
				380	0.5	350	N.H.
				400	0.15		
				410	N.H.		

Table I-5. Raw Data - Subject 5

Twin Grip		Gemini Loop		T-Bar		D-Ring	
250	19.5	175	11.25	230	19.25	165	18.0
275	16.25	200	8.0	250	15.5	200	8.5
295	3.25	225	3.75	275	14.0	230	2.0
300	2.5	250	N.H.	290	3.0	250	N.H.
325	2.25			300	2.25		
345	1.5			325	1.8		
365	0.15			345	1.0		
375	0.5			370	1.0		
395	0.6			390	0.5		
415	N.H.			415	0.5		
				430	N.H.		

Table I-6. Raw Data - Subject 6

Twin Grip		Gemini Loop		T-Bar		D-Ring	
315	24.7	325	11.5	370	8.5	325	4.2
360	9.25	370	10.75	400	4.3	350	2.5
400	2.9	400	6.5	430	8.1	385	N.H.
425	1.9	425	2.25	450	3.5	380	2.5
450	2.1	465	2.1	475	3.5	400	4.25
470	0.7	500	2.75	485	2.8	425	1.0
500	3.75			535	N.H.	455	1.0
						500	0.1

Table I-7. Raw Data - Subject 7

Twin Grip		Gemini Loop		T-Bar		D-Ring	
325	24.0	210	24.0	315	28.5	250	11.5
350	8.0	225	19.25	340	12.5	275	11.75
390	4.2	245	14.0	355	7.0	325	3.5
425	1.25	285	4.5	400	4.0	345	0.9
		310	4.25			350	2.0
		360	1.5			400	N.H.

Table I-8. Raw Data - Subject 8

Twin Grip		Gemini Loop		T-Bar		D-Ring	
315	21.0	265	22.0	310	25.0	220	30.0
360	4.7	275	4.5	325	30.0	250	15.75
370	7.5	300	2.75	380	5.25	280	7.0
385	6.5	325	N.H.	385	4.0	300	0.5
400	0.5			455	1.25	335	N.H.
450	1.25			470	3.5		
475	N.H.			485	N.H.		

Table I-9. Raw Data - Subject 9

Twin Grip		Gemini Loop		T-Bar		D-Ring	
310	29.0	210	26.5	365	15.5	250	24.0
330	24.5	225	20.75	385	12.0	275	7.5
370	5.25	250	30.0			310	0.5
395	4.5	275	5.0			325	0.75
395	4.25	300	1.75			365	0.4
410	3.5	325	1.25			365	1.3
		370	0.25			390	0.5
		400	N.H.			425	0.5
						450	N.H.

Table I-10. Raw Data - Subject 10

Twin Grip		Gemini Loop		T-Bar		D-Ring	
280	25.5	155	15.0	300	5.5	170	17.5
300	11.5	185	11.25			200	9.25
		200	5.5			230	8.25
		230	5.0			255	9.25
		255	3.5			275	3.0
		280	2.5			325	2.5

Table I-11. Raw Data - Subject 11

Twin Grip		Gemini Loop		T-Bar		D-Ring	
275	22.0	175	12.75			180	12.5
320	25.0	215	5.75			180	30 +
		230	6.75				

APPENDIX II

STATISTICAL PARAMETERS OF

GRIP RETENTION DATA

DEFINITION OF VARIABLES
(for Tables 8, 9, 10, 11, 12)

x_1 - Twin Grip

x_2 - T-bar

x_3 - D-ring

x_4 - Gemini Loop

y_1 - Twin combined* slope

y_2 - Twin combined log force @ $t = 0$

y_3 - Ring combined slope

y_4 - Ring combined log force @ $t = 0$

y_5 - $x_1 - x_2$ (slope)

y_6 - $x_3 - x_4$ (slope)

y_7 - $x_1 - x_2$ (log force @ $t = 0$)

y_8 - $x_3 - x_4$ (log force @ $t = 0$)

y_9 - $y_1 - y_3$ (slope)

y_{10} - $y_2 - y_4$ (log force @ $t = 0$)

*combined - average of two grips within either type (i.e. Twin or Ring)

x_1, x_2, x_3, x_4 may either be slope or log force @ $t = 0$

Table II-1. Linear Regression-Twin Grip

Subject (1)	Number of Observations (2)	Intercept (3)	Regression Coefficient (4)	Standard Error of Regression Coefficient (5)	Correlation Coefficient (6)	Standard Error of Estimate (7)	Log Force at Time - Zero $\frac{(3)}{(4)}$ (8)
1	8	279.326	-110.919	19.809	.916	3.944	2.5182
2	7	327.568	-128.705	16.394	.962	2.972	2.5451
3	8	180.017	-67.680	8.684	.954	2.667	2.6598
4	6	288.774	-115.372	28.421	.897	2.776	2.5029
5	9	238.792	-93.174	22.256	.845	4.181	2.5628
6	7	278.123	-103.858	28.532	.852	4.874	2.6779
7	4	464.010	-176.985	62.242	.895	5.531	2.6217
8	6	331.598	-125.983	35.737	.870	4.107	2.6320
9	6	604.562	-231.173	30.780	.966	3.353	2.6151
TOTAL	61						

Table II-2. Linear Regression-T-bar

Subject (1)	Number of Observations (2)	Intercept (3)	Regression Coefficient (4)	Standard Error of Regression Coefficient (5)	Correlation Coefficient (6)	Standard Error of Estimate (7)	Log Force at Time Zero - $\frac{(3)}{(4)}$ (8)
1	10	229.591	-90.463	16.509	.889	4.215	2.5269
2	7	236.610	-112.303	10.900	.977	2.590	2.5521
3	8	253.950	-96.157	27.682	.817	6.123	2.6409
4	9	196.521	-75.781	13.024	.910	2.853	2.5932
5	10	195.531	-75.965	15.016	.873	3.783	2.5739
6	6	113.399	-41.070	18.831	.737	1.900	2.7611
7	4	582.022	-223.539	81.740	.888	6.141	2.6036
8	6	396.795	-149.160	41.621	.873	6.844	2.6601
TOTAL	60						

Table II-3. Linear Regression-D-ring

Subject (1)	Number of Observations (2)	Intercept (3)	Regression Coefficient (4)	Standard Error of Regression Coefficient (5)	Correlation Coefficient (6)	Standard Error of Estimate (7)	Log Force at Time Zero $\frac{(3)}{(4)}$ (8)
1	9	118.396	-48.030	21.032	.653	7.693	2.4650
2	7	84.233	-34.372	1.837	.993	.573	2.4506
3	7	105.149	-43.179	4.959	.969	1.928	2.4351
4	7	117.610	-46.315	10.883	.885	2.653	2.5393
5	--	--	--	--	--	--	--
6	7	54.593	-20.117	6.591	.807	1.046	2.7137
7	5	202.008	-78.866	12.596	.964	1.626	2.5614
8	4	534.102	-215.544	12.167	.997	1.244	2.4779
9	8	211.885	-82.723	27.294	.776	5.633	2.5769
10	6	126.284	-49.677	10.856	.916	2.437	2.5421
TOTAL	60						

Table II-4. Linear Regression-Gemini Loop

Subject (1)	Number of Observations (2)	Intercept (3)	Regression Coefficient (4)	Standard Error of Regression Coefficient (5)	Correlation Coefficient (6)	Standard Error of Estimate (7)	Log Force at Time Zero - $\frac{(3)}{(4)}$ (8)
1	8	161.014	-67.339	11.270	.925	4.272	2.3910
2	8	108.568	-44.004	4.824	.966	2.122	2.4672
3	6	109.439	-44.361	11.028	.895	3.054	2.4670
4	6	123.193	-49.941	20.044	.780	4.415	2.4667
5	--	--	--	--	--	--	--
6	6	156.741	-57.702	13.409	.907	2.031	2.7163
7	6	252.395	-99.332	14.341	.961	2.855	2.5409
8	--	--	--	--	--	--	--
9	7	322.083	-127.078	34.159	.857	7.351	2.5345
10	6	121.227	-48.992	8.509	.945	1.803	2.4744
TOTAL	53						

Table II-5. Linear Regression-Composite Grip Statistics

Grip (1)	Number of Observations (2)	Intercept (3)	Regression Coefficient (4)	Standard Error of Regression Coefficient (5)	Correlation Coefficient (6)	Standard Error of Estimate (7)	Log Force at Time Zero $- \frac{(3)}{(4)}$ (8)
Gemini Loop	53	79.937	-30.132	5.930	.580	6.675	+2.65289
T-bar	60	171.272	-64.637	9.322	.673	6.895	+2.64973
Twin Grip	61	162.668	-61.368	9.346	.650	6.593	+2.6507
D-ring	60	76.394	-29.034	4.670	.632	5.587	+2.63122

Table II-6. Confidence Levels on Log Force at Time Zero

Grip	Number of Observations	Mean	Standard Deviation	Standard Error	95% Confidence Level
Twin	8	2.58922	.06599259	.0233319	2.53405 2.64440
T-bar	7	2.61546	.0795100	.03005195	2.54192 2.68899
Twin Composite	15	2.60147	.07120654	.01838545	2.56203 2.64090
D-ring	7	2.53181	.09634186	.03641380	2.44271 2.62092
Gemini Loop	8	2.50725	.09639083	.0340793	2.42666 2.58784
Ring Composite	15	2.51871	.09372512	.02419972	2.46681 2.57062
All Grips	30	2.56009	.09197594	.01679243	2.52575 2.59443

Table II-7. Confidence Levels on Regression Coefficient

Grip	Observations	Mean	Standard Deviation	Standard Error	95% Confidence Level
Twin	8	-122.108	48.1915	17.0383	-162.397 -81.8188
T-bar	7	-91.557	33.6942	12.7352	-122.719 -60.3949
Twin Composite	15	-107.851	43.5507	11.2447	-131.969 -83.7332
D-ring	7	-46.2733	18.8963	7.14213	-63.7495 -28.797
Gemini Loop	8	-67.3436	30.230	10.6879	-92.6167 -42.0706
Ring Composite	15	-57.5108	26.9879	6.96825	-72.4563 -42.5653

Table II-8. Log Force at Time Zero.

Subject #	x_1	x_2	x_3	x_4
1	2.5182	2.5269	2.4650	2.3910
2	2.5451	2.5521	2.4506	2.4672
3	2.6598	2.6409	2.4351	2.4670
4	2.5029	2.5932	2.5393	2.4667
5	2.5628	2.5739	--	--
6	2.6779	2.7611	2.7137	2.7163
7	--	--	--	2.5409
8	2.6320	2.6601	--	--
9	2.6151	--	2.5769	2.5345
10	--	--	2.5421	2.4744

Table II-9. Slopes.

Subject #	x_1	x_2	x_3	x_4
1	-110.919	-90.463	-48.030	-67.339
2	-128.705	-112.303	-34.372	-44.004
3	-67.680	-96.157	-43.179	-44.361
4	-115.372	-75.781	-46.315	-49.941
5	-93.174	-75.965	--	--
6	-103.858	-41.070	-20.117	-57.702
7	--	--	--	-99.332
8	-125.983	-149.160	--	--
9	-231.173	--	-82.223	-127.078
10	--	--	-49.677	-48.992

Table II-10. Differences between Grips within a Class.

Subject #	y_5	y_6	y_7	y_8
1	-20.456	19.309	-.0087	.0740
2	-16.402	9.632	-.0070	-.0166
3	28.477	1.182	.0189	-.0319
4	-39.591	3.626	-.0903	.0726
5	-17.209	--	-.0111	--
6	-62.788	37.585	-.0832	-.0026
7	--	--	--	--
8	23.177	--	-.0281	--
9	--	44.[illegible]55	--	.0424
10	--	-0.685	--	.0677
Mean	-14.9703	16.5006	-.029928	.029371
Standard Deviation	32.3335	18.2544	.041233	.045440
Standard Error of Mean	12.2209	6.89953	.015584	.0171748
95% Confidence Level	-44.8740 14.9334	-.382064 33.3832	-.068063 .0082058	-.012654 .071397

Table II-11. Differences between Classes.

Subject #	y_9	y_{10}
1	-43.0065	.90455
2	-81.3160	.08970
3	-38.1485	.19930
4	-47.4485	.04505
5	--	--
6	-33.5545	.00450
7	--	--
8	--	--
9	-126.5225	.05940
10	--	--
Mean	-61.6661	.0820833
Standard Deviation	36.0170	.0661186
Standard Error of Mean	14.7039	.0269928
95% Confidence Level	-99.[illegible]638 -23.8683	.0126[illegible]5 .151471

Table II-12. Grouped Statistics and Tolerance Limits.

Statistic	Twin Combined Slope	Twin Combined Log Force @ t=0	Ring Combined Slope	Ring Combined Log Force @ t=0
Mean - u	-115.559	2.60232	-60.1246	2.52010
Standard Deviation σ	51.3325	.067041	26.5706	.090328
Standard Error of Mean	18.1488	.023703	9.39412	.031936
95% Confidence Interval	-158.474 -72.643	2.54627 2.65837	-82.338 -37.911	2.44458 2.59562
Number of Observations	8	8	8	8
K Statistic for 90% Confidence @ 95% Tolerance	2.755	2.755	2.755	2.755
K	144.2	.18469	73.2	.24885
u-Kσ	-257.0	2.41763	-133.3	2.27125
u+Kσ	28.64	2.78702	13.07	2.76895

Table II-13. Average Values within Class.

Subject #	y_1	y_2	y_3	y_4	Age
1	-100.691	2.52255	-57.6845	2.4280	37
2	-120.504	2.5486	-39.188	2.4589	35
3	-81.9185	2.65035	-43.770	2.45105	23
4	-95.5765	2.54805	-48.128	2.5030	24
5	-84.5695	2.56835	--	--	21
6	-72.464	2.7195	-38.9095	2.7150	21
7	--	--	-99.332	2.5409	21
8	-137.5715	2.64605	--	--	20
9	-231.173	2.6151	-104.6505	2.5557	19
10	--	--	-49.3345	2.50825	43
Correlation Coefficient	.0485		.0735		

Table II-14. Age Regression

Dependent Variable	Intercept	Regression Coefficient	Standard Error of Regression Coefficient	Correlation Coefficient	Standard Error of Estimate
Twin Slope Combined	-169.001	2.08596	2.866	.285	53.149
Twin Log Force Combined	2.74571	-.0055958	.00317	.585	.0587
Rings Slope Combined	-102.20173	1.47639	1.068	.492	24.992
Rings Log Force Combined	2.68636	-.0058339	.00342	.571	.0801

Table II-15. Confidence Levels on Log Force at T = 5 seconds and T = 10 seconds

Subject #	Log Force @ t = 5 sec. y_1	Log Force @ t - 10 sec. y_1	Log Force @ t = 5 y_2	Log Force @ t = 10 y_2
1	2.47241	2.42224	2.33889	2.24971
2	2.50692	2.46523	2.32938	2.19983
3	2.58746	2.52453	2.33684	2.22258
4	2.49346	2.43880	2.39902	2.29498
5	2.50866	2.44892	--	--
6	2.65424	2.54052	2.54747	2.37988
7	--	--	2.49058	2.44025
8	2.60953	2.57292	--	--
9	2.59356	2.57193	2.50566	2.45558
10	--	--	2.40690	2.30555
Mean	2.55078	2.49927	2.41934	2.31854
Standard Deviation	.0617806	.062291	.085258	.0971873
Standard Error of Mean	.0218427	.022023	.0301435	.0343609
95% Confidence Interval	3.59914 2.60243	2.44720 2.55135	2.34806 2.49062	2.23729 2.39980

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